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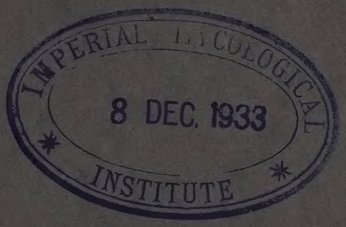
A Phytophthora Rot of Watermelon

By
J. G. Brown and M. M. Evans



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A Phytophthora Rot of Watermelon

By

J. G. Brown and M. M. Evans

About October 1, 1932, a watermelon which showed a rot disease was brought to us from a ranch near Marana, approximately thirty miles northwest of Tucson. According to the rancher who produced the fruit the disease was just becoming prominent at that time. Investigation was made by the junior author who found the rot in one acre of watermelons. Infected melons were found in all parts of the area, but they were more numerous in one spot. Apparently the disease had started in this spot and had spread in all directions. Later the entire field of 10 acres was affected.

ENVIRONMENT

No weather records are available for Marana, which is approximately 600 feet below the altitude of Tucson and in somewhat drier surroundings. The Weather Station (University) at Tucson reported traces of rain on September 20 and 23; 0.10 inch on September 25, and 0.13 inch on September 29,—a total measurable precipitation of 0.23 inch for the month preceding the appearance of the watermelon rot. For the eleven days preceding the discovery of the rot the maximum temperatures were 95 degrees F. on two days but mostly lower, reaching 84 degrees F. on September 30. During this time the minimum temperature reached 57 degrees F. which is cool for the month of September. The Meteorologist (3) reported for the State "a noticeable lowering of temperatures, beginning on the 19th."

The field concerned consisted of a medium heavy loam which is irrigated in order to produce a crop. A part of the field was planted to watermelons during the preceding season.

VARIETY ATTACKED

The variety of watermelon attacked by the disease was the wilt-resistant Iowa Belle, which was grown from seed obtained from the Iowa Melon Growers' Association. Since a large quantity of seed was purchased, widely distributed over Arizona, and no report of the rot has reached us from any other planting, the disease probably was not introduced with the seed. The crop was planted in April. During the summer in which the disease was discovered watermelons of the Klondyke variety were grown in an adjoining field, but no evidence of the fruit rot was seen. The Klondyke melons were plowed under before the rot appeared in the field planted to Iowa Belle.

By the middle of August the first crop of Iowa Belle melons was mostly harvested. Small, deformed fruits were picked and discarded but a few large, mature melons still remained in the field. Some of the vines were cut back and others were left untouched. The vines, which were in excellent growing condition, exhibited a good set of fruit for a second crop. However, the rot now came in and destroyed an estimated 40 to 50 percent of the fruits in the field. There also was a loss from the disease on melons sold in the local market, which is impossible to estimate.

SYMPTOMS

The symptoms of the disease were unusual for Arizona. Watermelons here are attacked by anthracnose *(Colletotrichum lagenarium)*, leaf blight *(Macrosporium cucumerinum)*, wilt *(Fusarium species,* commonly attributed to *F. niveum)*, and occasionally by Texas root rot *(Phymatotrichum omnivorum)*. At a glance the symptoms barred these diseases.

The disease attacked only the fruits. Infected melons had no lesions on the under side but were badly spotted on the exposed surface (Plate I, Fig. 1). The lesions were small, brown specks 2 to 4 millimeters in diameter when they first became apparent. They enlarged, became slightly depressed, and showed concentric rings of alternating brown with lighter bands in the skin of the melon (Plate I, Fig. 2). Later the rings were more distinctly marked by the growth of the hyphae on the light bands (Plate I, Fig. 3). The center of a spot was then white to pale gull gray* surrounded by a band of hair brown; around this was a band of pale pinkish buff to pinkish buff which consisted of sporangiophores (conidiophores) and sporangia (conidia); the outermost band was dark ivy green to blister brown. By this time the lesion was 3 inches or more in diameter. Gradually the mycelial growth spread entirely over the infected surface. The epidermis was weakened and easily peeled off. As the lesion enlarged the center of the circular spot sometimes cracked as a result of increased water loss through the injured epidermis. Small, immature fruits became blackened without exhibiting the concentric rings described for the ripe and ripening fruits.

The inward advance of the fungus kept pace with its superficial spread until the tissues of the melon became water-soaked and soggy. There was a definite margin between the infected and healthy tissues (Plate I, Fig. 4). The rate of growth of a lesion was determined on one fruit which was inoculated on October 13. On October 15 the lesion was 8 millimeters in diameter; on the 16th, 16 mm.; on the 17th, 27 mm.; on the 18th, 44 mm.; on the 19th, 54 mm.; on the 20th, 68 mm.; on the 21st, 83 mm.; on the 22nd, 100 mm.; on the 23rd, 115 mm. No odor was evident in the decaying tissues unless secondary infection with other organisms occurred.

*Ridgway, Robert—Color standards and color nomenclature—Washington, 1912.

CAUSE

MACROSCOPIC APPEARANCE

Infected watermelons which were placed in a moist chamber soon showed a luxuriant growth of white mycelium like that observed on melons in the field. Similar growth occurred on surface-sterilized plugs of infected tissues which were removed from the fruit to sterile media with a flamed scalpel. On the watermelons and in young cultures on the plugs the mycelium was closely appressed to the substrate; it much resembled very fine, damp cotton wool in which the fibrous nature is not evident. Later the cultures presented a finely granular appearance and turned pale pinkish buff to cinnamon in color.

MICROSCOPIC APPEARANCE

Under the microscope the living filaments of the fungus were non-septate, branching, hyaline, with numerous oil globules and granules in the cytoplasm (Plate II, Figs. 11, 12). The hyphae were also studied in sections made by killing blocks of cultures with the mycelium in situ on oat-meal agar and running the blocks through a close series of alcohols, alcohol-xylol, and into paraffin, after which they were cut and the sections stained with iron alum-haemotoxylin. The sections showed a dense plectenchyma of more or less angular hyphae in the medium, with a loose layer of hyphae above. In the latter primary hyphae were mostly between 4.4 μ and 8.5 μ in diameter. Twenty nuclei in the vegetative hyphae averaged 1.05 μ in diameter; the largest measured was 1.37 μ and the smallest was 0.91 μ.

RELATION TO HOST TISSUES

The hyphae of the parasite were both inter- and intracellular (Plate III, Figs. 27, 26) in prepared slides of the infected tissues of the watermelon. None of the tissues appeared to be resistant to the growth of the fungus. Filaments were found even in the wood vessels. Occasionally the hyphae traversing the intercellular spaces simply developed haustoria through the walls of adjacent cells; more often the main hyphae passed through one or more cells in which they freely branched.

The parenchyma cells composing the soggy, infected pulp of the fruit were without visible contents other than the filaments of the parasite when they were stained with the iron alum-haematoxylin. Attacked epidermal and neighboring cortical cells were plasmolyzed. The guard cells of stomata were frequently pushed far apart by the aggregated conidiophores which produced conidia just outside (and sometimes within) the enlarged stomatal aperture and chamber.

ASEXUAL REPRODUCTION

Sporangiophores and sporangia were abundant in the loose upper layer of young cultures as well as on the surface lesions of watermelons in the field, in the moist chamber, and uncovered

in the laboratory. They were few on inoculated potato-dextrose agar, but abundant over a period of several weeks in a flask of autoclaved chicken feed consisting of mixed grains. None was found at any time on oat-meal agar.

The sporangiophores on media were loosely branched (Plate III, Fig. 23); on the surface of infected melons they were mainly simple (Plate II, Fig. 13). Sporangia were typically papillate, citriform bodies, but the shape varied from approximately spherical and almost reniform to spindle-shaped and cylindrical sacks (Plate II, Fig. 14). In a few cases the sporangia were situated just above a slight swelling in the sporangiophore, which was much less conspicuous than that found in *Phytophthora infestans*. One hundred sporangia obtained from the surface of a watermelon gave an average length of 37.2 μ and an average thickness of 23.9 μ; extremes in length of the sporangia were 52.1 μ and 21.5 μ; extremes in their breadth were 36.8 μ and 17.1 μ; the ratio of their length to breadth varied from 0.96 to 1.7, about 58 percent showing ratios from 1.23 to 1.44.

Conidia which germinated upon the surface of the watermelon put out one or more germ tubes, often several, which soon branched (Plate II, Fig. 16). When only one germ tube was produced it usually, but not always, grew from the papillary end of the conidium. A conidium might put out lateral germ tubes (Plate II, Fig. 16 a). When ripe, the conidia carried with them, in breaking off, a part of the stalk on which they developed. Occasionally this stalk repaired the wall at the broken end and grew into a branching hypha (Plate II, Fig. 16 b). The behavior of the conidium in this spurious germination could not be determined, but the extent of the branching from the stalk in some cases and the appearance of the conidial contents suggested that the conidium must be supplying energy and material for growth. Instead of a regular germ tube, some conidia formed a short hypha with another conidium at the end (Plate II, Fig. 16 c).

Conidia which were placed in a drop of water lost their derived nature and became sporangia. The zoöspores which they organized were reniform to pyriform and spherical, and unequally biciliate. Usually the zoöspores were formed inside the sporangium, but again they might form after the protoplasmic content had flowed out into a thin membrane beyond the pore of the sporangium. (Plate III, Figs. 18, 19, 20). As a rule they were held for a time within the everted membrane, but sometimes they escaped singly directly from the sporangium (Plate II, Fig. 17). After a short period of activity (Plate III, Fig. 21) the zoöspores became quiescent and, after rounding off (Plate III, Fig. 22), produced a filament which soon branched into a mycelium.

Sphaero-conidia were abundant among the sex organs in old cultures but infrequent in the sporangia-producing stage of young cultures. They were hyaline to pale yellow or straw color. Those among the sporangia were seen to germinate like conidia (Plate

III, Fig. 25); they were abundantly supplied with granular contents, like the sporangia, when viewed in the living condition (compare Fig. 24, Plate III, with Fig. 15, Plate II). Of the sphaero-conidia among the sex organs the greater number were not unlike the neighboring oögonia in the appearance of their living contents, but fully one-third of those observed contained internal spores in various stages of development. The spores were evidently potential or actual resting spores. Development of the internal spores was followed in stained preparations. The cytoplasm became thin around irregular masses of the living substance (Plate III, Fig. 28) in which one to four nuclei were included. The masses of cytoplasm then rounded off. The internal spores thus formed either germinated at once (Plate III, Fig. 29), or they secreted a thick wall and became resting spores (Plate III, Fig. 30). This behavior of the sphaero-conidia does not appear to have been reported.

SEXUAL REPRODUCTION

Oögonia and antheridia were developed on oat-meal agar in the course of four weeks. They were very numerous in a somewhat flat, thin region on the surface of the substrate or at a varying distance above it (Plate III, Fig. 31). Occasionally they were somewhat scattered. None was found on the watermelon. The oögonia were both terminal (Plate III, Fig. 32; numerous figures, Plate IV) and intercalary (Plate IV, Fig. 45) in position, although very few of the latter were found. In one case two oögonia were terminally placed on the forked end of a hypha. Two two-celled oögonia were found (Plate IV, Fig. 44). The antheridia were all paragynous in type and terminal in position (Plate III, Fig. 32; Plate IV), club-shaped, or short and irregularly rounded. Those observed grew from a hypha which produced only antheridia. Contact with the oögonium was made anywhere between the oögonial base and the equator of the oögonium, seldom higher.

The oögonia were pear-shaped to sub-spherical when viewed from the side, hyaline when young and pale yellow when mature. They showed early vacuolization of the cytoplasm (Plate IV, Fig. 33) and parietal placing of the numerous nuclei. The organization of the oöplasm was often indefinite, although a definitely larger, centrally placed nucleus was present in most oögonia (Plate IV, Fig. 37). Sometimes considerable contraction of the cytoplasm had taken place and only a small amount of periplasm was evident about most of the peripheral nuclei (Plate IV, Figs. 40, 43). The total amount of stainable cytoplasm was surprisingly small in a few oögonia, even at fertilization (Plate IV, Fig. 43). Thirty-five oögonia at and just before fertilization ranged in length from 29.6 μ to 50.3 μ with an average length of 40.6 μ; in breadth they varied from 25.2 μ to 44.9 μ with an average of 34.9 μ.

The antheridia were less numerous than the oögonia in the material studied. They appeared to behave according to the description of their development by other observers in the matter of nuclear division, differentiation of a functional male nucleus, and fate of the supernumerary nuclei. Exceptionally, an occasional antheridium showed little or no difference in the size of the nuclei at maturity (Plate IV, Fig. 42).

Fertilization, so far as the mechanism of communication of the antheridium with the oögonium is concerned, differed from the classical description (1) which appears to have been found to apply by most investigators. The development of an antheridial tube (Plate IV, Figs. 42, 43) of pronounced type was the exception in our slides. Even when an antheridial tube was present neither "receptive spot" nor "manocyst" (4) appeared in the oögonial wall. The sequence of events appeared to be as follows:

Contact of the antheridial and oögonial walls (Plate IV, Figs. 35, 36) is followed by a softening of the oögonial wall (Plate IV, Fig. 41) and probably also of the antheridial wall. The softening frequently results in a visible thickening of the former, as shown in the drawing referred to. The antheridium may then push a tube through the softened spot in the oögonial wall. More often, however, the two walls unite at the place of contact, and an aperture forms which connects the cavities of the two sex organs (Plate IV, Figs. 37, 38, 39, 40, 44). Union of the walls may be so perfect that the transition from the antheridium to the oögonium is smooth (Plate IV, Fig. 38), or there may be a distinct difference in the thickness of the walls at the place of juncture (Plate IV, Figs. 40, 44). Following the communication between the cavities, the functional male nucleus and some cytoplasm of the antheridium pass over into the oögonium (Plate IV, Figs. 37, 38, 39, 40). Further events in the process of fertilization were not followed.

Only one oöspore was found in our material which was mostly in the pre-fertilization and fertilization stages. The oöspore showed that several of the supernumerary nuclei of the oögonium were included in the cytoplasm of the former; the oögonium retained an unusual amount of periplasm (Plate IV, Fig. 46).

CULTURES

Pure cultures of the fungus were grown on oat-meal agar, corn-meal agar, and potato-dextrose agar made up according to the directions given by Tucker (6). The cultures grew well at room temperatures and at 28 degrees C. in the incubator. Little difference was noticeable in the fair, white growth on the three media. However, the sporangia were absent or scarce in all cultures except as previously noted, and very numerous on the surface of the watermelon, although the opposite was true with reference to the sex organs. Oögonia and antheridia developed on all three media when the cultures were two to four weeks old.

INOCULATIONS

The following inoculations were made with a pure culture of the fungus which was isolated from the watermelon rot. All inoculations were run at 28 degrees C.

POTATO

Tuber inoculated November 8; no results.

Growing plant discolored at and around inoculation, but effect evanescent.

TURNIP

Fleshy root inoculated November 10; in *two days* irregular sunken area around puncture, wood brown; surface of lesion covered with cottony mycelium 1-2 mm. deep; in *four days* same surface appearance but lesion enlarged; cross section showed invasion 21 mm. deep, mottled white and pale olive to buff.

SWEET POTATO (Plate I, Fig. 9)

Fleshy root inoculated November 10; in *two days* lesion 27 mm. in diameter, irregular, slightly sunken, Saccardo's umber, in *six days* same surface appearance, but lesion spread over half of the surface of the root; cross section showed mottling of Rhodes brown and Van Dyke brown as contrasted with Congo pink of healthy flesh.

BLUE AGAVE* (Plate I, Fig. 10)

Excised leaf inoculated November 7; in *three days* surface lesion a dark purplish gray with a mottling of vetiver green and mouse gray to dark mouse gray as contrasted with the natural color of gnaphalium green; in *seven days* center of lesion dark quaker drab to sooty black with mottling of mouse gray, next band mouse gray to deep mouse gray, then band of dark quaker drab to sooty black with mottling of deep mouse gray and mustard yellow; border next to healthy tissue, mustard yellow; distinct line between diseased and healthy tissues.

AGAVE AMERICANA VAR. MARGINATA

Excised leaf inoculated November 7; in *three days* lesions 41-44 mm., deep purplish gray mottled with mouse gray as contrasted with normal color of light celandine green to agave blue.

CEREUS SCHOTTII

Excised stem inoculated November 7; in *three days* lesions 2-7 mm., slightly elevated, definite margin, blackish slate as con-

*Southwestern botanists usually consider this plant to be *Agave americana*. Our station botanist, Professor J. J. Thornber, disagrees.

trasted with normal color of vetiver green; in *nine days* lesions 6-8 mm., otherwise like preceding; cross section at *nine days* showed lesions 15-23 mm. deep, primrose yellow but turning mikado brown in a few minutes, as contrasted with normal internal color of pale veronese green.

LEMON

Fruit inoculated November 4; no results.

ORANGE

Fruit inoculated November 12; in *one day* water-soaked lesion 37 mm. in diameter with sayal-brown center 7 mm. across; around this an area 11 mm. in diam., pinkish buff; next band 19 mm. in diam., cinnamon buff; normal color of surface, cadmium orange; cross section showed water-soaked appearance which blended with healthy tissues.

TOMATO (Plate I, Fig. 5)

Green fruit inoculated November 12; in *one day* water-soaked lesion 11 mm. in diam.; center of lesion 7 mm. in diam., pale pinkish buff, outer part 4 mm. in diam., cinnamon buff; in *two days* lesion 37 mm. in diam., same colors as contrasted with normal color of light viridine green; cross section showed no difference in color between diseased and healthy tissues.

Ripe fruit inoculated November 4; in *five* days no change in color but softening of tissues and appearance of mycelium on surface.

Growing plant shrunken and constricted at place of inoculation and for several inches above and below at end of *three days;* plant killed above infected spot.

BELL PEPPER (Plate I, Fig. 5)

Green fruit showed a small, water-soaked spot around needle-puncture in *one day;* entire fruit water-soaked in *five days* and surface mostly covered with sporangium-bearing mycelium.

PEAR (Plate I, Figs. 7, 8)

Ripe fruit inoculated November 8; in *two days* lesion slightly sunken, 12 mm. in diam., mars brown to blister brown; in *four days* lesion 35 mm. in diam.; in *six days* 47 mm. in diam.; long section at this time showed lesion 42 mm. deep, cinnamon brown to wood brown, with a more or less definite line between diseased and healthy tissues.

APPLE, ROME BEAUTY

Ripe fruit inoculated November 4; in *six days* lesions extensive, mars brown, slightly sunken at point of inoculation; definite margin between infected and healthy tissues.

APPLE, BELLEFLEUR (Plate I, Figs. 7, 8)

Ripe fruit inoculated November 8; in *two days* lesion 25 mm. in diam.; in *four days* lesion 60 mm. in diam., argus brown center surrounded by cinnamon buff; in *six days* lesion 61.5 mm. in diam., extending almost entirely through apple, verona brown.

APPLE, YELLOW NEWTOWN (Plate I, Figs. 7, 8)

Ripe fruit inoculated November 8; in *two days* lesion 16 mm. in diam., clay to verona brown; in *four days* lesion 40 mm., same color; in *six days* lesion almost through apple, 54 mm. in diam., 59 mm. deep, sayal brown to blister brown.

CUCUMBER (Plate I, Fig. 6)

Green fruit inoculated November 10, in *two days* sunken area 22-27 mm. diam. x 2-3 mm. deep around needle-puncture; no change in color. At the end of *four days*, fruit removed to moist chamber, room temperature; *two days* later deeply sunken lesion covered with white mycelium showing abundant sporangiophores and sporangia; most of flesh invaded, pale cendre green as contrasted with white flesh of healthy tissues.

Note.—After this paper was prepared for publication specimens of corn plants were received which showed lesions at the base of the stalk. From the lesions on some plants we isolated a species of Phytophthora. The material led us to try inoculations on growing corn with the watermelon Phytophthora. At the end of *five days* infections have resulted in a few inoculated plants, but growth is slow and the lesions are, so far, unlike the natural infections found in the specimens from the field.

RESUMÉ OF CHARACTERISTICS

Lesions	*Cultures*	*Hyphae*	*Sporangiophores*
Exposed surface, watermelon fruits; concentric rings later covered with white matted growth; abundant sporangia (conidia).	Fungus grows at 28 degrees C. on oat-meal agar, corn-meal agar, potato-2 percent dextrose agar, steamed watermelon plugs.	Non-septate, inter- and intracellular, branched; primary hyphae 4.4 μ- 8.5 μ diameter in cultures.	Simple on host, loosely branched on media; rarely show swelling below attachment of sporangium.

Sporangia (conidia)	*Oögonia*	*Antheridia*
Typically citriform, but vary from spherical to cylindrical; non-papillate to papillate; 37.2 μ x 23.9 μ; approximately 58 percent show ratio of length to breadth between 1.23 and 1.44.	Abundant on oat-meal and corn-meal agars, 2-4 weeks; mostly terminal; sub-spherical to pyriform; 40.6 μ x 34.9 μ about time of fertilization.	Paragynous, club-shaped, or short and irregularly rounded.

Sphaero-conidia	*Pathogenicity*
One type present in sporangium phase of cultures, hyaline to straw color, germinates like conidia; a second type abundant among sexual cell-organs, often forms internal spores which may become resting spores; latter type resembles oögonia in size and color.	Fungus attacks, besides green and ripe watermelons, ripe fruits of apple, pear, orange, and tomato; green fruits of tomato, bell pepper, and cucumber; storage roots of turnip and sweet potato; leaves of *Agave americana* var. marginata and Blue Agave; stems of tomato and *Cereus schottii*. It is non-pathogenic for potato tubers and lemon fruits.

IDENTIFICATION OF THE FUNGUS

The fungus here described as the cause of a watermelon rot generally agrees with the description of *Phytophthora cactorum* (6). It produces a matted growth on corn-meal and oat-meal agars; it shows abundant sporangia (conidia) which, although variable, generally conform in shape and fall within the measurements cited (5, 6); sex organs are abundant on oat-meal agar in two to four weeks; the antheridia are paragynous; sphaero-conidia are present; it attacks many kinds of plants.

Of the species of Phytophthora which are virulently pathogenic for apples, namely, *P. arecae, P. boehmeriae, P. cactorum, P. capsici, P. cinnamomi, P. citricola, P. citrophthora, P. hibernalis, P. hydrophila, P. meadii, P. mexicana, P. nicotianae, P. palmivora, P. parasitica,* and *P. syringae,* only *P. cactorum, P. citricola, P. hibernalis,* and *P. syringae* are known to produce paragynous antheridia predominantly (6, p. 43); of these species, *P. citricola* is regarded by Tucker as a form of *P. cactorum* (6, p. 148) and *P.*

hibernalis is placed with *P. syringae* (6, p. 165). Both *P. hibernalis* and *P. syringae* fail to grow at 27.5 degrees C., but *P. cactorum* grows well at that temperature, thus agreeing with our Phytophthora on watermelon. *Phytophthora citrophthora* does not produce oögonia, so far as known, and it attacks lemons, which are characteristics that apparently rule the species out of consideration here; likewise *P. meadii* and *P. palmivora* do not show oögonia in cultures. The foregoing comparative facts appear to place the watermelon Phytophthora with P. cactorum.

The watermelon fungus, in its non-pathogenicity for the potato tuber, disagrees with some results obtained with *Phytophthora cactorum*. In Tucker's work almost all inoculations of tubers with the latter produced rot, although one strain, Number 192, failed to give infection, as did also *P. citricola* which Tucker regards as a form of *P. cactorum*. However, pathogenicity for the potato tuber is regarded by Tucker as a characteristic of *P. cactorum*. On the other hand De Bary (2) reported the species to be non-pathogenic for the potato.

Our watermelon fungus was virulently pathogenic for green and ripe tomato fruits; also for half-grown tomato plants. Tucker reports *P. cactorum* to be slight to severe in infective power when inoculated into green tomato fruits and lists the species under all three headings, "virulently pathogenic," "very weakly pathogenic," and "non-pathogenic." In general he regards *P. cactorum* as "usually weakly to non-pathogenic."

Although the Phytophthora on watermelon agrees with *Phytophthora cactorum* in producing numerous oögonia in cultures, the oögonia of the former appear to be considerably larger. The oögonium illustrated in Plate IV, Figure 43, is 56 μ long from the top to the upper end of the stalk; the one shown in Figure 38 is 45.9 μ in greatest diameter; the oögonium illustrated in Figure 37 is 17.9 μ. The three measurements are examples of the extremes found in cultures of the watermelon fungus; they indicate a wide range in the size of the oögonia. Our average of 40.6 μ x 49.9 μ is considerably larger than the averages given by Tucker and Rosenbaum, respectively.

Tucker gives "extreme" and "average" diameters of oögonia. Although he says (6, p. 150) that the oögonia are pyriform or subspherical, he fails to state just what his extreme and average diameters are. Obviously pyriform and subspherical bodies have extreme transverse and extreme longitudinal diameters. If Tucker's figures apply to the length rather than the thickness, then the oögonia described for *P. cactorum* are much smaller than those of the fungus on watermelon. He gives as extreme diameters 38.4 μ and 17.5 μ, with an average of 27.9 μ. Rosenbaum (5) records one oöspore of *P. fagi* in the class 41.5 μ to 43.49 μ; since the oögonia are larger than the oöspores, the maximum diameter of

the former must have approximated the diameter shown by our Figure 38. Tucker includes *Phytophthora fagi* with *P. cactorum*.

Although there are differences the Phytophthora on watermelon agrees more closely, taxonomically, with *P. cactorum* than with any other described species. *Phytophthora cactorum* has not been reported on the watermelon (7), but attack on this host may have been suspected.*

DISCUSSION

Although *Phytophthora citrophthora* is present in southern Arizona, the appearance of *P. cactorum* in a naturally arid environment is somewhat surprising. The fungus has not been found in the State before, so far as we know. Watermelons have been grown in Arizona for years, and there are many other hosts here which have been attacked by the fungus in other parts of the United States. The high temperatures of mid-summer, as well as the dry air, may explain the absence of losses in the summer crops of susceptible plants. The appearance of the rot in Arizona in October and a similar rot in California at the same time of year suggests that climatic factors may be important.

The fungus which we have described presents some interesting features. Absence of an antheridial or fertilization tube in the greater number of fertilization stages studied is one of these. In reviewing the literature dealing with the cactorum group of Phytophthora, one is inclined to suspect insufficient investigation of the sex act with modern laboratory facilities. Failure to find a fertilization tube is usually referred to poor preparations. Careful study of good serial sections probably would reveal a condition in other species of Phytophthora similar to that found here. The formation of the manocyst and fertilization tube has been explained on the basis of different osmotic pressures in the oögonium and antheridium (4), which may be correct. However, that there should always be just the proper differences in osmotic pressure in the sex organs at the proper time appears illogical,—a conclusion supported by the appearance of our material.

Another interesting feature is the presence of at least two kinds of sphaero-conidia in the watermelon Phytophthora. The smaller sphaero-conidia, most numerous among the sporangia and conidia, may be chlamydospores or related in some way to the conidia; the larger sphaero-conidia certainly appear to be

*The following anonymous note in the California Agricultural Experiment Station Report, 1927-28, suggests in the last sentence that the author suspected the fungus might be *cactorum* rather than *citrophthora*: "A new host is reported for *Phytophthora citrophthora*. After the late rains last fall, in October, many watermelons, squashes, and some pie pumpkins were infected producing characteristic brown lesions. A comparative study of *Phytophthora cactorum* isolated from different hosts is being undertaken."

related to the oögonia. The formation of internal spores which may become resting spores suggests the parthenogenetic development of an oögonium harking back to the Albugo blitii type. Occasional reports of antheridia accompanying sphaero-conidia strengthen the evidence for the oögonial relationship of the puzzling structures.

SUMMARY

1. A fruit rot of watermelon is described which occurred in October on the second crop. The disease is attributed to *Phytophthora cactorum*. This paper appears to be the first report of the species on watermelon.

2. The variety of watermelon attacked by the rot is the wilt-resistant Iowa Belle grown on irrigated land amid arid surroundings.

3. Symptoms of the disease are small brown specks 2 to 4 millimeters in diameter which enlarge, become slightly depressed, and form concentric rings of alternating brown and lighter bands. The lesion is eventually covered with a white mycelium. The flesh becomes water-soaked and darkened.

4. Results of macro- and microscopic studies of the fungus are given, including the relation to the host tissues and reproduction; also cultural reactions of the fungus and its effect on various inoculated plant parts and plants.

5. New features are described for the mechanism of fertilization and for sphaero-conidia.

6. The study is illustrated with four plates.

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PLATE I.

Fig. 1. Naturally infected watermelons in the field.

Fig. 2. Lesions on fruit before the external appearance of the fungus; 11 days after artificial inoculation.

Fig. 3. Later appearance of the lesions shown in Figure 2; mycelia growing on the surface 12 days after inoculation.

Fig. 4. Cross section of naturally infected fruit; most of the upper half of the flesh is soggy.

Fig. 5. Inoculated ripe tomato fruit (left) and green bell-pepper fruit (right) 6 days after needle-puncture.

Fig. 6. Surface and internal views of green cucumber fruit 6 days after inoculation.

Fig. 7. Ripe Bartlett pear (a), Bellefleur apple (b), and Yellow Newtown apple (c), 2 days after inoculation.

Fig. 8. Long sections of the fruits shown in Figure 7, 6 days.

Fig. 9. Surface and internal lesions in sweet potato root 6 days after inoculation.

Fig. 10. Leaf of Blue Agave 7 days after inoculation.

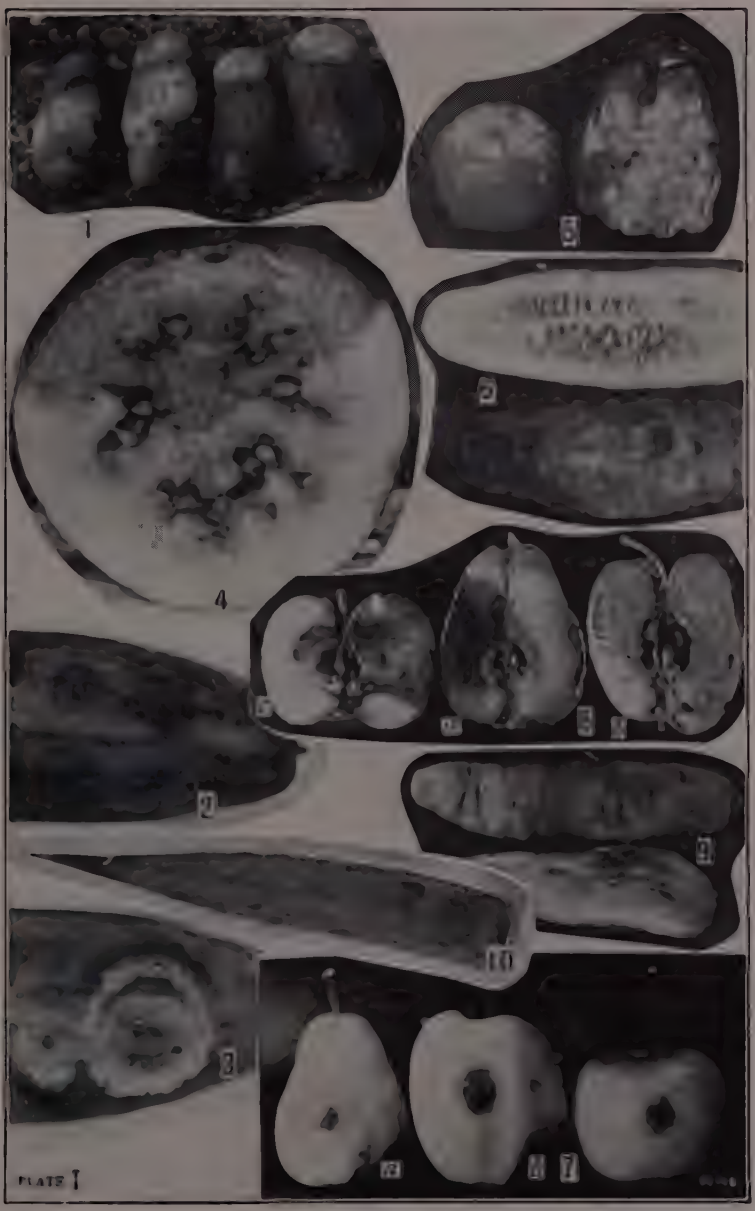
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PLATE I

PLATE II. All drawings from living fungus.

Fig. 11.	Branching of hypha.	x 455
Fig. 12.	Piece of living hypha,—branching and oil drops.	x 1087.5
Fig. 13.	Simple sporangiophore (conidiophore).	x 558.5
Fig. 14.	Forms of sporangia (conidia).	x 558.5
Fig. 15.	Living sporangium (conidium): granular nature of cell contents.	x 558.5
Fig. 16.	Germinating conidia.	x 558.5
Fig. 17.	Sporangium with a few remaining zoöspores, one caught in the opening.	x 558.5

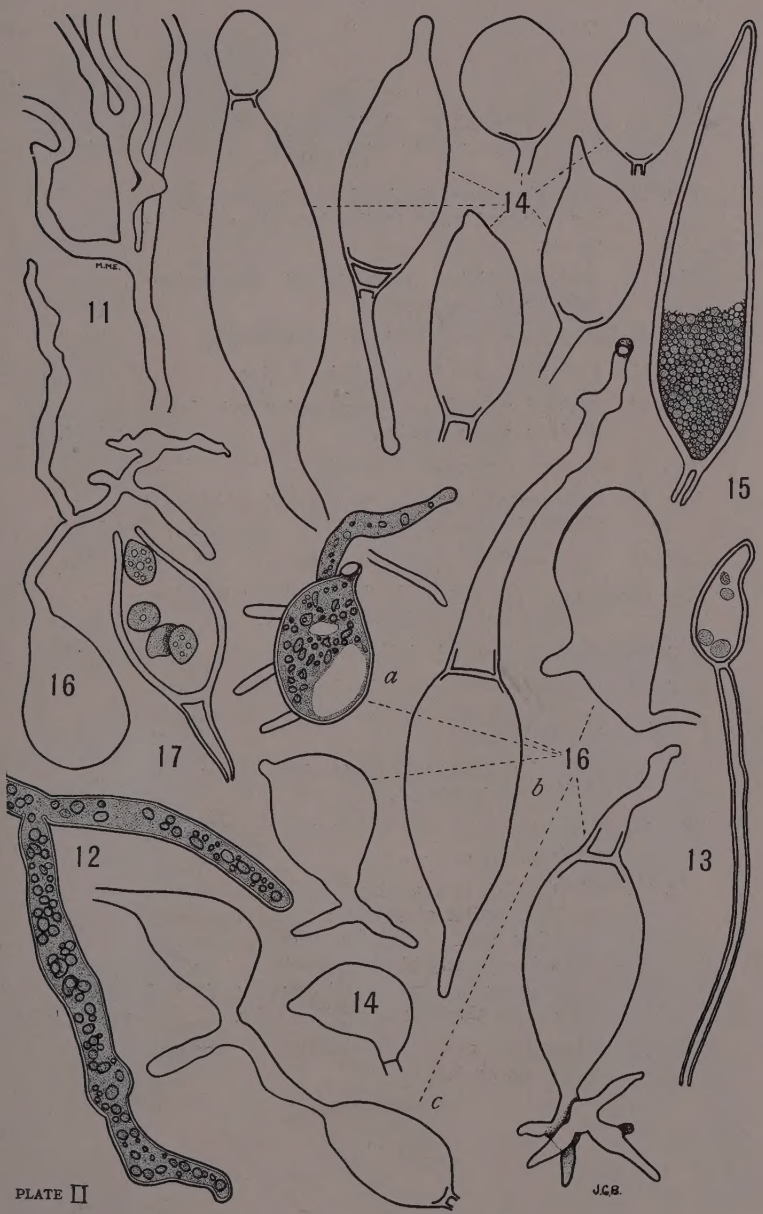

PLATE II

PLATE III. Figures 18, 19, 20, 23, 24, 25, 30, and 32, drawn from living fungus; other figures from stained preparations.

Fig. 18. Protoplasmic contents of a sporangium flowing outward prior to the formation of zoöspores. x 560.5

Fig. 19. Undifferentiated contents of sporangium held by a membrane. x 560.5

Fig. 20. Zoöspores formed within the membrane. x 560.5

Fig. 21. Free zoöspores from a stained slide. x 1087.5

Fig. 22. Stained zoöspore with granular cytoplasm, nucleus, and vacuoles. x 1087.5

Fig. 23. Sporangiophore from culture. x 108.7

Fig. 24. Sphaero-conidium from sporangium-bearing phase of culture. x 560.5

Fig. 25. Germinating sphaero-conidium. x 477.

Fig. 26. Piece of a hypha in intracellular position, one end in plasmolyzed host cell. x 1087.5

Fig. 27. Piece of hypha in intercellular space. x 1087.5

Fig. 28. Oögonium-like cell with protoplasm rounding off,—early stage in the development of internal spores. x 1087.5

Fig. 29. Oögonium-like cell containing spores, one spore germinating. x 1087.5

Fig. 30. Oögonium-like cell containing thick-walled resting spores. x 1087.5

Fig. 31. Distribution of sexual cell-organs in stained vertical section of culture: made by photographing section, inking photomicrograph, and subsequently bleaching print. a. hyphae in medium; b. zone containing oögonia and antheridia, also oögonium-like cells. x 1087.5

Fig. 32. Oögonium and antheridium in contact, oögonium on left. x 1087.5

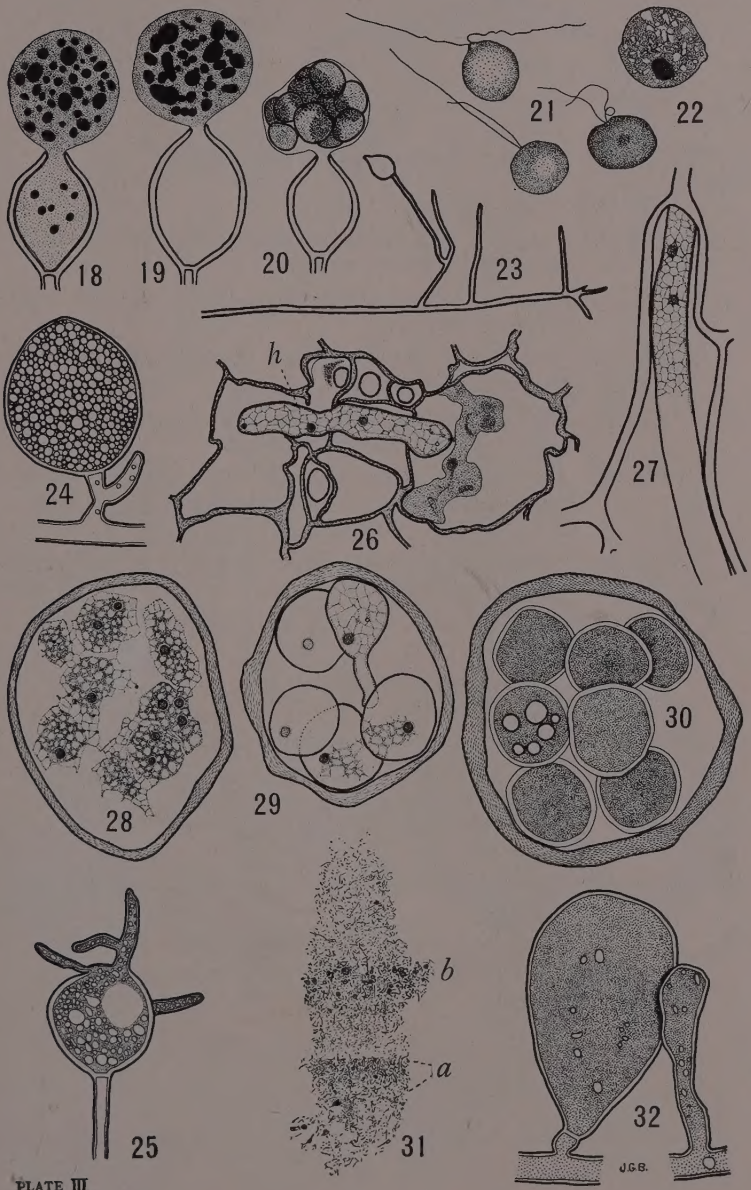

PLATE III

PLATE IV. All figures from stained slides; x 1087.5.

Fig. 33. Young oögonium.

Fig. 34. Oögonium with central functional nucleus and disintegrating peripheral nuclei.

Fig. 35. Stage in which walls between oögonium and antheridium begin to soften.

Fig. 36. Antheridium indenting wall of oögonium; latter is probably intercalary.

Fig. 37. Plasmogamy; softened walls have broken down between oögonium and antheridium.

Fig. 38. Another view of plasmogamy; the protoplasmic strand mentioned by de Bary is conspicuous in the antheridium.

Fig. 39. Later stage in plasmogamy; nucleus from antheridium has entered the oögonium.

Fig. 40. The oögonial nuclei show little difference in appearance.

Fig. 41. Softening of the oögonial wall at place of contact with antheridium.

Fig. 42. Penetration of oögonial wall by the antheridial tube.

Fig. 43. Oögonium abnormally poor in protoplasmic content; antheridial tube pushing membrane of protoplast inward; disintegrating nuclei clinging to wall of oögonium.

Fig. 44. Two-celled oögonium; wall between cells left unhatched.

Fig. 45. Intercalary oögonium.

Fig. 46. Oögonium containing oöspore and considerable periplasm.